BALL—Bringing Advanced eLectricity to Life

Fuel Cells Newsletter

Issue 2 2Q 2000

In This Issue

Operation Strong Angel Runs Strong

On June 10-15, Ball Aerospace & Technologies Corp.’s Fuel Cell Portable Power Systems (PPS) team participated in Operation Strong Angel, a multination humanitarian collaborative effort between military and civilian organizations. One of the goals of Operation Strong Angel was to foster partnerships between government and private sector organizations so they could develop an operational global response capability. Another goal was to foster collaboration between military forces of varying nations to more effectively respond to disasters and administer relief efforts. Strong Angel (www.strongangel.org) was a part of the RIMPAC military exercises, with U.S. efforts coordinated by LCDR Eric Ramussen, Fleet Surgeon of the U.S. Navy’s 3rd Fleet. Ball was invited to participate by the Defense Advanced Research Projects Agency (DARPA).

The variety of participants in Strong Angel was indicative of the type of operation expected in a real emergency requiring international cooperation and relief efforts. The participants included DARPA, the Red Cross, the Office of U.S. Foreign Disaster Assistance, the Office of the Secretary of Defense, RIMPAC, the United Nations, United Nations Children’s Fund (UNICEF), the United Nations High Commissioner of Refugees, the World Food Programme, COMTHIRDFLT, MAGTF-3, PACFLT, PACOM, SOUTHCOM, MSC, MERCY, BUMED, the Army, the Air Force, COE, PAHO, and other humanitarian organizations. There were also six Pacific Rim countries participating (Australia, Canada, Chile, Japan, Korea, and the United States) along with Great Britain.

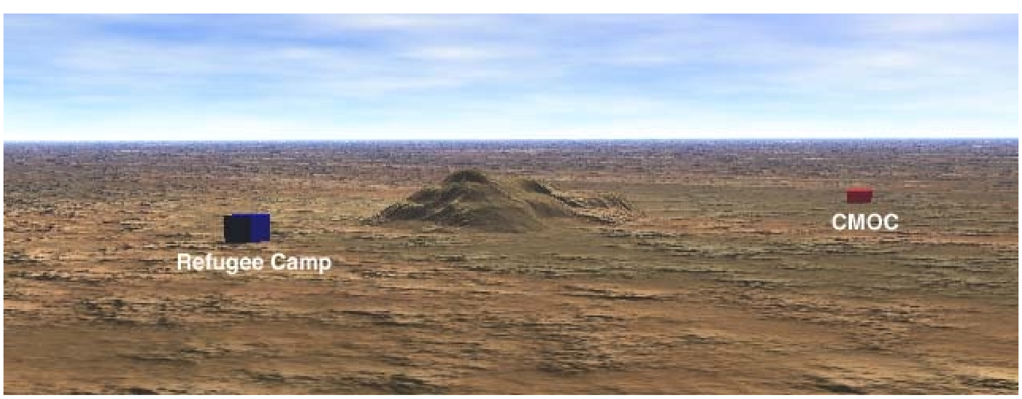
Strong Angel simulated a realistic event where tensions were mounting in one part of the world, resulting in military maneuvers and creating civilian refugees. The Red Cross recruited volunteers to serve as refugees and live in the simulated camp during the period of the exercise. Food, shelter, health care, and activities were provided for the refugees.

There were four team members from the portable fuel cell power systems participating: Bob Nowak of DARPA, Kris Gardner of the Communications and Electronics Command (CECOM), and Tim Quakenbush and Rich Reinker of Ball Aerospace. Ball took three 50-watt PPSs and three 100-watt PPSs to the exercise. Four of the six units were used, with a spare for each fuel cell class. CECOM, SOCOM, ARL, DARPA and Ball provided the fuel cells for the exercise.

The site for the Strong Angel refugee camp was a dry, dusty, desert area about 2 miles south of Waimea on the big island of Hawaii. The big island’s topography ranges from a desert-like environment to a rainforest environment, within just a few miles.

The Civilian Military Operations Center (CMOC), where all of the communications took place, was on one side of the site’s hill. The refugee camp, where the majority of the humanitarian effort took place, was on the other side. The exercise began on June 9 with the blessing of the site and the exercise participants in a traditional Hawaiian ceremony.

Exactly how the fuel cell power systems would be used was ambiguous prior to the start of the exercise. Possible applications involved prototype medical and language translation technologies, and their uses could not be defined until the volunteer refugees and participants started to interact. The fuel cell team assembled several switching voltage converters to match the wide range of possible load requirements.



Site for the Strong Angel activities.

PPS Fuel Cells and Solar Arrays Fill Power Needs

Organizations were beginning to set up in earnest on June 10. The Marines were busy handling some unexpected problems and were not able to get the generators running until late that day. As a result, the DARPA power sources teams were asked to provide initial power. The solar array and fuel cell systems powered many of the computers, servers, and laptops until the generators were brought online. The generators produced unwanted surges, however, so most of the computer equipment was left on alternative power for the duration of the Strong Angel exercise. Fuel cell systems, because they provide DC electricity and are not subject to AC motor anomalies, do not produce surges in the output power to users. This is one added benefit of using alternative power over diesel generators.

A PPS-100 was set up with a 24 to 115 VAC inverter to power three notebook computers for the language translation group.

A PPS-100 powers three notebook computers while the camp generator setup was delayed. The computers are translating spoken phrases between U.S. and Korean military officers.

Fuel Cells Supply Power in the Experiment Tent

The main activities involving the PPS were in the experiment tent where the TIDES project was being set up. TIDES, or Translingual Information Dissemination with Extraction and Summarization, can provide the military and the United Nations with unprecedented aid in understanding the social climate in which they work. TIDES is programmed currently to record accented and conventional English from broadcasts around the world. Accessing the database provides U.S. forces and others on the network with a preview of their operations from the point of view of other nations and ethnic groups. Such information can be valuable in gauging the kind of reception forces may receive when they arrive in a country. DARPA wanted to test this new project in the most realistic, challenging, and severe environment that they could find. Strong Angel was an excellent opportunity for several new products to be tested.

It became clear while setting up the equipment in the experiment tent that locally controlled power is a crucial factor in situations such as Strong Angel. The fuel cells fit exactly that niche. They provided continuous power that was not sensitive to the external power cables strung across the campground, which were constantly being disconnected.

Two PPS-100s were wired in parallel, with diode protection, to produce 22 V at a maximum current of 10 A. The power was routed through the 24 to 115 VAC converter and finally to seven notebook computers and two network hubs. Each device had its own power adapter to convert the 115 VAC back to the required DC voltages. The power was converted to AC because the laptops operated off various DC voltages. Converting to AC is much less efficient, but allows a wider range of computers to be operated. The number of laptops used ranged from zero to eight. When all of the laptops were operating, each fuel cell averaged 80-watts draw. An additional 24 V to 12 V converter was added to the PPS pair to run a small lamp and to charge mobile phones.

Two PPS-100s producing electrical power for notebook computers and network hubs for the TIDES project. The 24 V to 12 V converter is between the pair of PPSs, a 24 to 115 VAC converter is under the table, 12 V sockets for battery charging are in the upper-right corner, and the cap of the exhaust water collection bottle is in the bottom center.

PPS Fuel Cells Unaffected by Airborne Dirt

The experiment tent was a very dirty environment. The very fine-grained dirt in the area is from decomposed volcanic rock. The dust collecting on all surfaces did not affect the PPS-100's performance, and the water collected from the PPS-100 exhaust did not contain visible contamination. The filters on the fuel cell air intake are 70 mm nylon mesh. The filter mesh size on the additional fine mesh screen behind the internal air pump was selected to block particles smaller than the air orifices in the stack. Although the fuel cell systems did not require special handling, the personnel in the camp had to use goggles and dust masks to cope with the high levels of airborne dirt. The 100-watt fuel cells operated continuously in the harsh, extremely dusty environment for over 73 hours each.

One of the presentations in the experiment tent. The multitude of spots in the picture is from the camera flash reflecting from the airborne dirt in the tent. The network hubs and three of the seven computers using fuel cell power are on the table.

Rich Reinker of Ball Aerospace checking the status of the fuel cells. The goggles and dust mask were necessary equipment in the camp. The four notebook computers used as network servers are under the plastic cover in the background. The bottle in the lower right was collecting potable water from the fuel cell exhaust.

Experiment Tent Power and Fuel Details

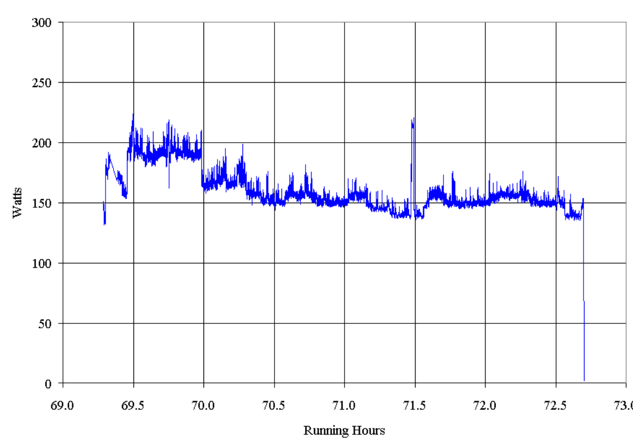
The PPS-100s ran for 73 continuous hours with one shut down on June 12. A high-power photographic lamp was plugged into the fuel cell power strip and both the PPSs shut down with current limit messages. Removing this load and restarting both units by pressing the reset button returned both systems to normal service.

A typical day

Each morning during the exercise, the computers were brought online, the TIDES system was tested, and several presentations were given to officers and the press. All of this activity was done using fuel cell power. The first operation that the notebook computers performed was to charge the internal battery. The graph shown below illustrates the power draw of a day in the experiment tent.

At 69.3 hours, a Dell notebook computer was plugged into the 24 V power with a 24 V to 19 V converter. The Dell was used to record data from the PPS-100s. The Dell started charging its internal battery and the total PPS power jumped up to 190 W. The PPS power declined as the Dell battery reached capacity. More of the TIDES personnel arrived and plugged in their computers at 69.5 hours. At this point, there were eight notebook computers and two network hubs running from fuel cell power. The PPS power jumped up to 220 W and tapered off to about 195 W. The Dell was removed from PPS power at 70 hours to ensure that there was room for any unexpected power surges during the presentations, such as the surge at 71.5 hours. The drop at 72.7 hours occurred when the computers were disconnected at the end of the last presentation.

The fuel used during the exercise was high-purity hydrogen (grade 5) in 290 ft^3 S bottles. Using high-purity hydrogen rather than less expensive industrial-grade hydrogen eliminated the need for integrating an activated charcoal filter approved for high pressure into the system. An "S" bottle is very similar to the industry standard "K" bottle. It is a few inches taller, has higher pressure, and contains more fuel. Some of the possible applications required using the portable 9 ft^3 fuel bottle, which was filled directly from the larger cylinders. A summary of the power demand, fuel usage, and cost for the two PPS-100s in the experiment tent is shown in the following tables.



Power output from the two PPS-100 fuel cell power supplies connected in parallel. The horizontal axis is hours since the fuel cells were turned on.

Power loads, power levels, and duration of the fuel cell power in the experiment tent. These values reflect the daily cycle of power draw between June 11 and June 14.

Elements of Fuel Cell Power Usage	Value	Units
Notebook Computers (with AC to DC converter)	7	
Notebook Computer (with DC to DC converter)	0 to 1	
Network Hubs (with AC to DC converter)	2	
24 VDC to 115 VAC converter	1	
Cell Phone (with DC to DC converter)	1	
Total Energy Produced	4637	Wh
Peak Surge Power	250	watts
Mean Power to Loads	63.5	watts
Total Running Time	73	hours
High-Demand Mean Power	120	watts
High-Demand Duration	24	hours
Low-Demand Mean Power	35.9	watts
Low-Demand Duration	49	hours

Actual cost of operating two PPS-100s in the experiment tent.

Actual Fuel Costs for Grade 5 H_2	Each	Sub-total	Units
No. of H_2 bottles in CMOC	2		
No. of days bottles were in the field	6		
Fuel Cost (High purity H_2)	$236.13	$472.26	per S bottle
Shipping (Honolulu to Waimea)	$9.29	$18.58	per S bottle
Bottle Rental	$0.22	$1.32	per S bottle/day
Activated Carbon Filter (not used)	$0.00	$0.00	
Sales Tax	$10.22	$20.44	
Total Cost		**$512.60**	
H_2 Purchased	290	580	ft^3 H_2
H_2 Used		140	ft^3 H_2
Energy Produced		4637	Wh
Cost per Energy of H_2 Purchased		$0.11	$/Wh
Cost per Energy of H_2 used		**$0.0267**	$/Wh

Cost estimate of using industrial-grade hydrogen instead of high-purity hydrogen. These estimates assume that two 290 ft^3 bottles of high-purity hydrogen were replaced with two 178 ft^3 bottles of industrial grade hydrogen with the addition of activated carbon to fill a pair of filters. (H_2 gas prices in Hawaii are higher than in the continental U.S.)

Estimated Industrial Grade H_2 Costs	Each	Sub-total	Units
No. of bottles in CMOC	2		
No. of days bottles in field	6		
Fuel Cost (Industrial Grade H_2)	$42.78	$85.56	per K bottle
Shipping (Honolulu to Waimea)	$9.29	$18.58	per K bottle
Bottle Rental	$0.22	$1.32	per K bottle/day
Activated Carbon (for Filters)	$7.5	$15.00	
Sales Tax	$1.85	$3.70	
Total Cost		**$123.16**	
Fuel Purchase	178	356	ft^3 H_2
Fuel Used		140	ft^3 H_2
Energy Produced		4637	Wh
Cost per Energy of H_2 Purchased		$0.027	$/Wh
Cost per Energy of H_2 Used		**$0.0104**	$/Wh

Hybrid Fuel Cell, Solar Array, Fuel Battery Drive a Ham Radio System

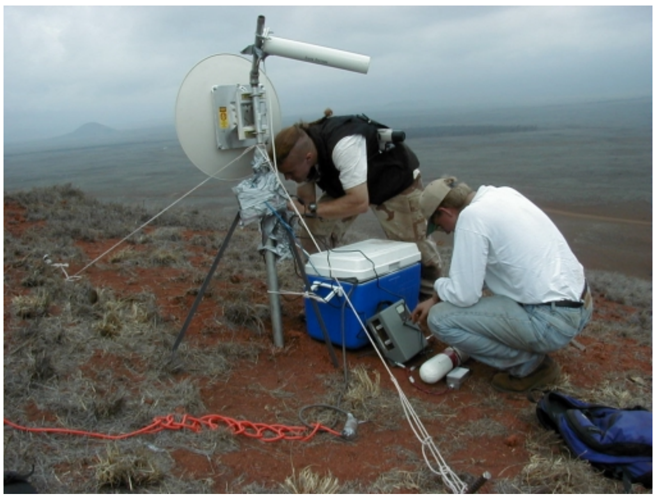
In addition to powering laptops at the CMOC, two additional pieces of equipment were powered at the refugee camp. A 50 W, 12 V fuel cell (PPS-50) was used in a parallel hybrid configuration with a 25 W solar array (P3-28V) to recharge two BB-390 nickel metal hydride batteries powering a set of short-wave radio equipment. The 2m ham radio was used to communicate around the world. The portable hydrogen bottle was used for this application. In

Ham radio equipment receives power from a hybrid system composed of a PPS-50, P3-28 solar array, and two BB-390 rechargeable batteries. The system was operated in the refugee camp.

many emergency situations, ham radio operators are the first to provide emergency communications. Both the solar array and the fuel cell kept the batteries charged for several days. On one occasion the 50 W fuel cell shut down due to a hydrogen leak detection error. This unit is being reviewed carefully in the lab. The unit was replaced with a spare and operated successfully until the end of the exercise. This is the first known use of photovoltaic and PEM fuel cells in parallel.

Fuel Cell Provides Power for a T1 LAN Relay

The second piece of equipment operated near the refugee camp was a T1 LAN relay for the refugees and experimenters from the CMOC to the refugee camp on top of Puu Paa.



A PPS-100 powers a T-1 phone/data relay station on the top of Puu Paa. This hill is about 300 ft above the refugee camp. The portable fuel bottle and PPS-100 were carried in a daypack up the hill.

A 24 V to 19 V voltage converter was used to match the fuel cell power to the requirements of the modems. The cylinder antenna was pointed at a similar device in the refugee camp, and the dish antenna was aimed at the civil/military camp a few miles away. The pair of modems consumed about 13 W continuously.

Fuel Cells Continue to Be an Option for the Military

The PPS-50 and PPS-100 fuel cell power systems performed extremely well during Operation Strong Angel. The fuel cell power systems remain a strong option for the military for their communication and electronics needs. LCDR Eric Ramussen noted that the fuel cells provided silent, efficient power and clean water as a by-product of combining hydrogen and oxygen.

Operation Strong Angel was a realistic field exercise for Ball's fuel cell power systems. Both the PPS-50 and PPS-100 exceeded all performance requirements. ◇

Ball Works with LANL on Direct Methanol Fuel Cells

Fuel Cells 2000, an industry association, recently announced in their June 28, 2000, release that Ball Aerospace & Technologies Corp. is actively involved with Los Alamos National Laboratories (LANL) in integrating their direct methanol fuel cell stack into a high-integrity system similar to that of the current genre of PPS products. *Los Alamos National Laboratory has scaled up its direct-methanol fuel cell (DMFC) from a 5-cell to a 30-cell stack that has been delivered to Ball Aerospace for system integration on a DARPA project.* The first 30-cell stack delivered to Ball was integrated into an engineering breadboard for initial system development. This unit allowed for the initial setup of the DMFC system and is now back at Los Alamos for testing. Ball is set to receive a second 30-cell fuel cell stack from LANL at the end of July to continue the development. An engineering model system is expected at the end of this calendar year with a prototype unit slated for mid-2000. DARPA sponsors the work taking place at Ball. ◇

New Information Available on the Web

We are adding new information to Ball's PPS website, so please check the site often. The address is
http://www.ball.com/aerospace/cryfc.html ◇

Frequently Asked Questions

Here are answers to questions that have been asked by users of Ball's fuel cell portable power systems concerning application of the PPS systems. Special acknowledgements to USSOCOM.

Is it possible to connect two PPS fuel cells in series to increase the voltage or in parallel to increase the max current?

Yes, the PPS-50 and PPS-100 fuel cell power supplies can be connected together with the correct protection. A larger output current is available with a parallel connection, and larger output voltage is present with a series connection. The following table contains a list of possible voltages and currents for several configurations. Please contact Ball for special applications or questions.

Available output voltage and current with different configurations of PPS-50 and PPS-100 power supplies.

Configuration	Vout at No Load	Vout at Full Load	Amps at Full Load	Full Load Watts
Single PPS-50	16	11	5	55
Two PPS-50s in series	32	22	5	110
Two PPS-50s in parallel	15.5	10.5	10	105
Single PPS-100	30	23	5	115
Two PPS-100s in series	60	46	5	230
Two PPS-100s in parallel	29.5	22.5	10	225
PPS-50 and PPS-100 in series	46	34	5	170
PPS-50 and PPS-100 in parallel	DO NOT DO THIS			

How is the EMI shielding handled for a PPS?

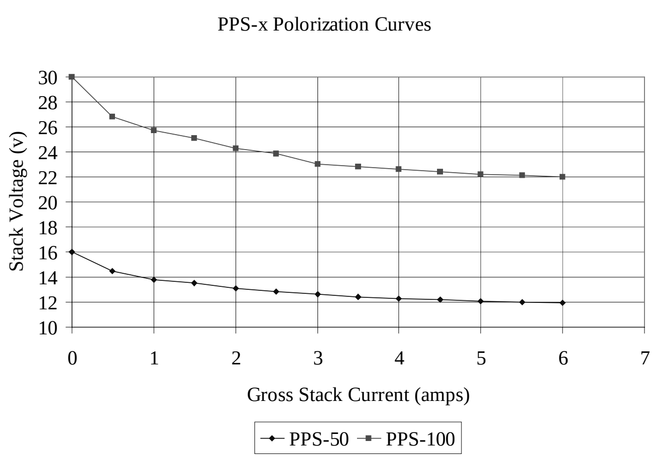
There are two paths for electromagnetic interference (EMI) associated with the PPS-100 and PPS-50: Radio frequency radiation near the PPS, and through the power cable. EMI can be an issue for the PPS when received from equipment in the nearby environment, and an issue for the equipment receiving interference from the PPS.

EMI carried through the power cable has been a problem when powering PRC-119 radios. Placing inductive filters on the power cable a few inches away from the connector that plugs into the PPS can squelch the interference in the cable.

What is the output voltage range of a PPS-50 and a PPS-100?

The output voltage of each PPS-x depends on the current demand of the load, stack temperature and how well the stack is hydrated.

The graph in the figure contains polarization data from a PPS-50 and PPS-100 under typical operating conditions in the lab. The upper curve is from a PPS-100 and the lower curve is from a PPS-50. The net current available to the load can be up to 10% less than the gross current.



What are efficient voltage converters and regulators for the PPS-50 and PPS-100?

The output of fuel cell power supplies is not always matched to devices that require power. Many notebook computers accept 18 V to 20 V, which is above the PPS-50 output and below the PPS-100 output. There are a vast number of switching voltage converters. The word *switching* refers to the method used to switch the input power at high frequencies (1 kHz to 100 kHz range) to maintain a constant output voltage on a set of capacitors. They are commonly available with a wide input voltage range and a well-regulated fixed output voltage independent of the current. The efficiency of switching voltage converters is between 75 and 95%. Common values are from 80 to 90%.

Two of these converters were used in the Strong Angel exercises to match DC voltage requirements of several applications. Efficient DC to AC converters were also used in Strong Angel. The table below contains converter details.

The PROwatt 250 with 12 V input has an upper limit of 15 V and the PPS-50 can produce 16 V with no load. There have been fuel cell users that have had similar problems with other voltage converters. A 15 V zenir diode, such as NTE5191A from NTE Electronics, placed across the input leads will protect the voltage converter. ◇

Events

October 30 - November 2, 2000 — 2000 Fuel Cells Seminar, Portland, Oregon

Newsletter Contributors

Kris Gardner
Communications and Electronics Command
U.S. Army CECOM

Tandy Dilworth
Ball Aerospace & Technologies Corp.

Timothy Quakenbush
Ball Aerospace & Technologies Corp.

Contact Information

Tandy Dilworth
Ball Aerospace & Technologies Corp.
Products and Technology
P.O. Box 1062
Boulder, CO 80306-1062
(303) 939-4215
tdilwort@ball.com
http://www.ball.com/aerospace/cryfc.html

Voltage converters that have been used with PPS-50 and PPS-100 fuel cell power supplies. Technical details are available from the manufacturers.

Device	Manufacturer & Distributor	Input Voltage	Output Voltage	*Max Current*
VI-J03-CX	Vicor Corp. www.vicr.com	10 V to 20 V	Adjustable 12 V to 24 V	3.2 A 6.4 w/booster
VI-213-EV		21 V to 32 V	Adjustable 12 V to 24 V	6.3 A
PROwatt 250	StatPower www.statpower.com	11 V to 15 V or 20 V to 30 V	115 VAC 60 Hz modified sin	2.2 A
PROwatt 250i	VIT Electronics www.vitelectronics.com		230 VAC 50 Hz modified sin	1.1 A